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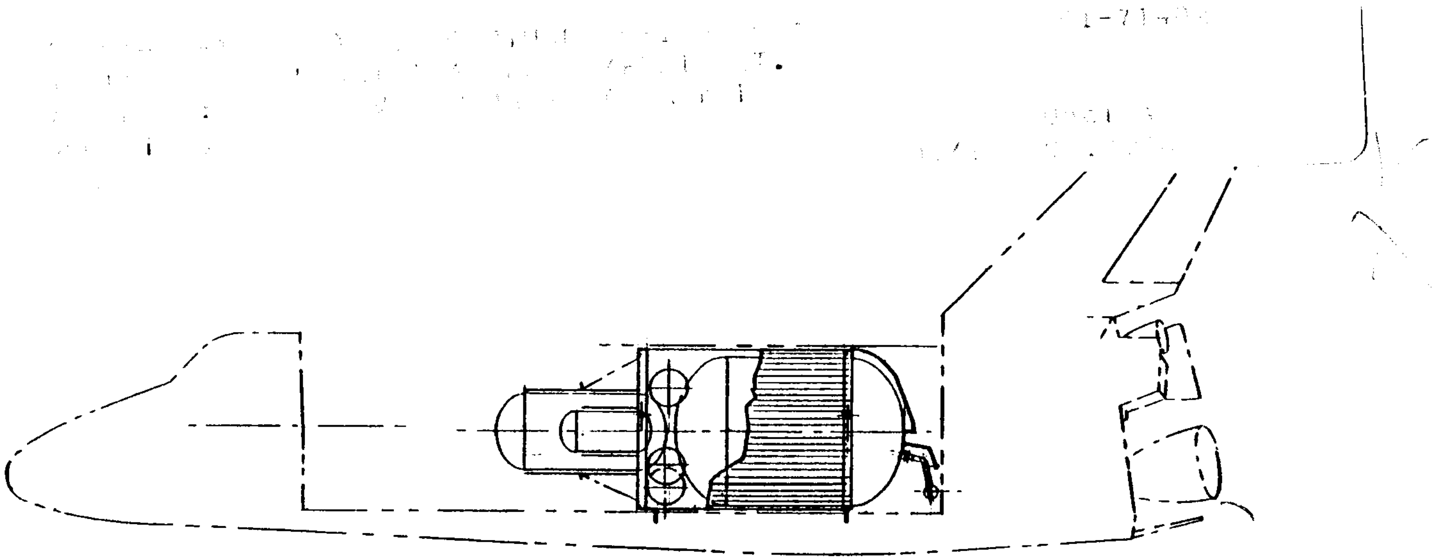

CONCEPTUAL DESIGN OF AN ORBITAL PROPELLANT TRANSFER EXPERIMENT

VOLUME I • EXECUTIVE SUMMARY

GENERAL DYNAMICS
Convair Division

VOLUME I	EXECUTIVE SUMMARY
VOLUME II	STUDY RESULTS

NASA CR-165150
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CONCEPTUAL DESIGN OF AN ORBITAL PROPELLANT TRANSFER EXPERIMENT

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August 1980

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Under
Contract NAS3-21935

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FOREWORD

This report, consisting of Volume I Executive Summary and Volume II Study Results, summarizes the technical effort conducted under Contract NAS3-21935 by the General Dynamics Convair Division from May 1979 to July 1980. The contract was administered by the National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio.

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All new data are presented with the International System of Units as the primary system and English Units as the secondary system. The English system was used for the basic calculations. Some NASA source data from previous studies used English units. These data are presented in English units as originally documented in the contractor reports.

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SUMMARY

The primary objective of this study was to provide the NASA Lewis Research Center with a conceptual design and development plan for a large scale orbital propellant transfer experiment. The scope of this effort was twofold. First, OTV configurations, operations and requirements planned for the period from the 1980's to the 1990's were reviewed and a propellant transfer experiment was designed that would support the needs of these advanced OTV operational concepts. Second, an experiment development plan was prepared to aid NASA LeRC in the preparation of an overall integrated propellant management technology plan for all NASA centers.

The following table summarizes the basic findings of this study regarding: 1) compatibility of the experiment concept with planned OTV development and operational scenarios, and 2) the meeting of the primary experiment objectives along with the flexibility to perform many secondary, as well as presently undefined experiments in the propellant management technology area.

THE CONCEPTUAL EXPERIMENT DESIGN SATISFIES A BROAD RANGE OF OTV PROPELLANT MANAGEMENT SCENARIOS

- SINGLE STAGE/SINGLE BURN/MULTI-BURN
- MULTI-STAGE/MULTI-BURN
- PROPELLANT TANKS (LH_2 - LO_2) WET OR DRY
- SHUTTLE OR DEPOT REFUELING BASE
- MISSIONS OF SEVERAL DAYS TO SEVERAL MONTHS
- SUBSYSTEM VARIATIONS - PRESSURIZATION, INSULATION, VENTING ACQUISITION, ABORT DUMP

THE CONCEPTUAL EXPERIMENT DESIGN PROVIDES A HIGH DEGREE OF EXPERIMENT FLEXIBILITY

PRIMARY OBJECTIVES	SECONDARY OBJECTIVES	SUPPORTING RESOURCES
FILL LINE CHILLDOWN TANK PRECHILL RECEIVER TANK FILL	PRESSURIZATION (He) PROPELLANT ACQUISITION TANK INSULATION TVS START BASKET REFILL/ PERF. ABORT DUMP	– ZERO-G MASS GAUGING – MODIFIED OTV GROUND SUPPORT EQUIPMENT FOR INTERFACE OF EXPERIMENT LH_2 & He REQUIREMENTS

THE CONCEPTUAL EXPERIMENT DESIGN REPRESENTS AN EXPERIMENTAL TOOL TO INVESTIGATE THE PROPELLANT TRANSFER TECHNOLOGY REQUIREMENTS OF A BROAD RANGE OF SPACE-BASED OTVs

The development program for this experiment starting with the phase C/D effort is three years. The preliminary cost estimate (for planning purposes only) is \$56.7M, of which approximately \$31.8M is for Shuttle user costs.

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INTRODUCTION

1.1 SCOPE

With the continued development of the Space Transportation System (STS) the free world is on the threshold of a new and expanding space era. Some of the challenging space programs being proposed include space construction bases, large antenna systems, solar powered satellites, and propellant depots. The commonality within these diverse programs is the use and need of orbital transfer vehicles (OTV) to support the development and ultimate operational phases of these space activities. In turn the OTV has the requirement for space based re-fueling in order to effectively carry out its assigned function.

The area of propellant management and in particular that of orbital propellant transfer of cryogens has long been identified as a critical technology area by the NASA LeRC and Convair. A family of precursor studies, both NASA sponsored and independently pursued by Convair provide the basis for this, the ultimate experimental program.

1.2 OBJECTIVES

The objectives of this study were to define the largest practical experiment scale of an OTV propellant tank that could be accommodated within the cargo bay of a single Shuttle flight. This scaled OTV propellant tank became the focal point for the conceptual design of an orbital propellant transfer experiment and the definition of the companion development plans and cost estimates.

1.3 CONDUCT OF STUDY

This study contained four major task areas which are briefly described below. The description also indicates the report sections which provide the details of the study effort.

TASK I - Survey of OTV Concepts & Requirements (See Section 2.0)

Task I of the study effort provided mission requirements and OTV configurations based on previous NASA study results. Emphasis was on defining the propellant management requirements for on-orbit resupply and operations of the OTV during a typical mission. Figure 1-1 is an example of a propellant transfer scenario involving the use of space-based OTVs.

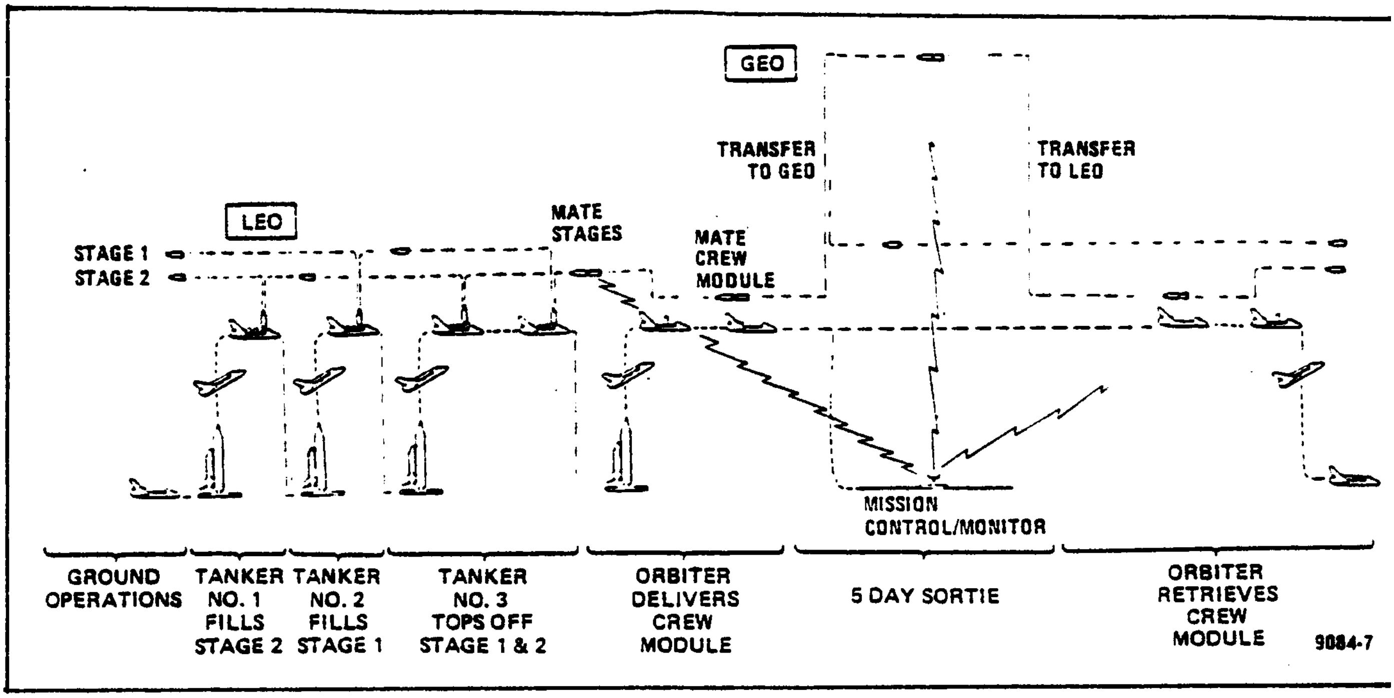


Figure 1-1. OTV Propellant Transfer Scenario

Task II - Preliminary Experiment Definition (See Section 3.0)

Task II provided the preliminary experiment definition of the experiment configuration, test fluid, instrumentation, and both ground and orbital testing procedures. In addition, potential secondary objectives (i.e., insulation evaluation, demonstration of pressure control technique) were established. The experiment was sized to meet the above objectives in an economical manner; however, the maximum size of the experiment was restricted to the total volume of the cargo bay of the Shuttle. The recommended experiment approach was presented to NASA for approval before proceeding with Task III. Figure 1-2 outlines the preliminary testing areas and the flow schematic that was defined.

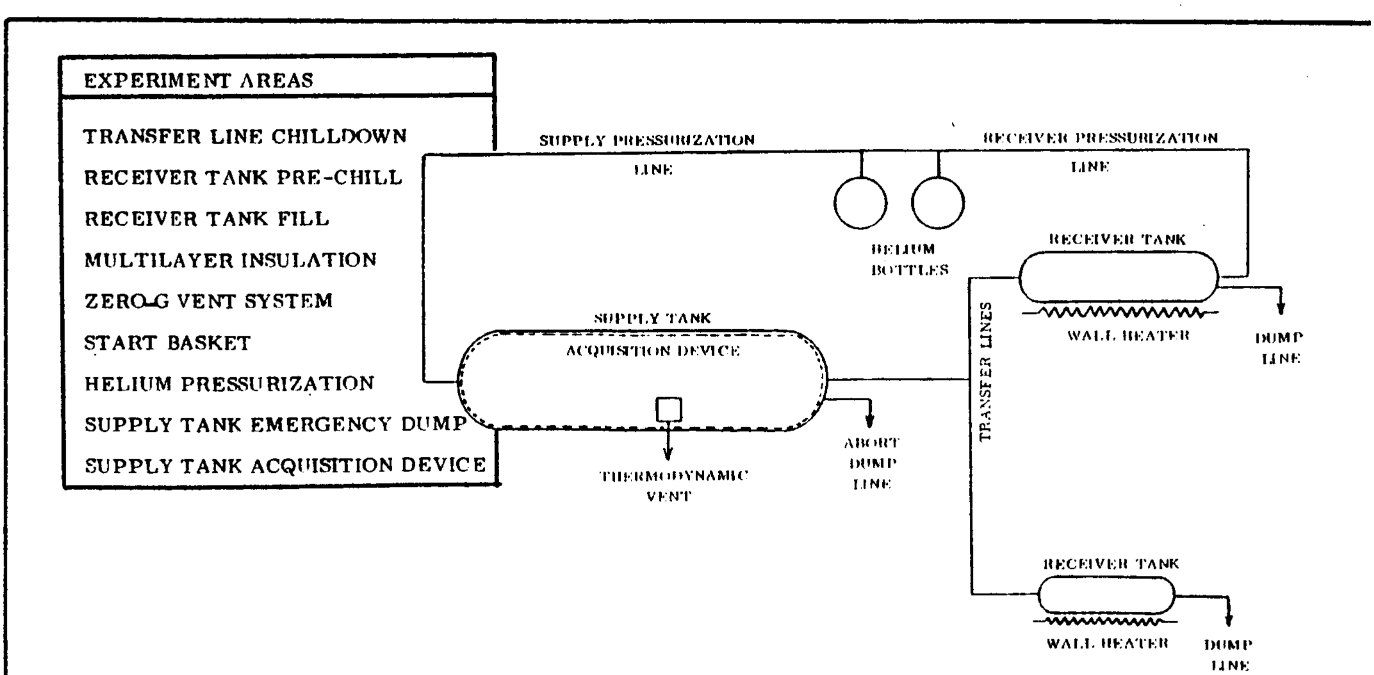


Figure 1-2. Typical Propellant Transfer Experiment System

Task III - Conceptual Design of Experiment (See Section 4.0)

Task III provided a conceptual design of the recommended propellant transfer experiment to the depth of detail necessary to allow cost estimates and schedules to be generated. In addition, the ground and inflight operational procedures required to perform the experiment were defined. Figure 1-3 provides the overall experiment installation concept and weight summary that was defined.

EXPERIMENT ELEMENT	WEIGHT KG	(LBS)
SUPPLY TANK SYSTEM	752.3	(1652)
1/2 SCALE RECEIVER TANK	131.9	(291)
1/4 SCALE RECEIVER TANK	49.4	(109)
PRESSURIZATION SYSTEM	725.6	(1600)
INSTRUMENTATION & WIRING	181.4	(400)
SUPPORT STRUCTURES	1097	(2419)
CONTROLS, RAU, DISPLAYS	145.1	(320)
TOTAL DRY WEIGHT	3082.7	(6791)
TOTAL WET WEIGHT (LH_2 & He)	8253.5	(18199)
PLUS ENERGY KIT (840 KWH)	740.1	(1632)
SUPPORT ELEMENTS		
RCS PROPELLANT	725.6 Kg (1600 LB)	
ELECTRICAL ENERGY	47.4 Kw-h	
ORBITAL EXPERIMENT TIME	3 + DAYS	
SECONDARY EXPERIMENTS	6	

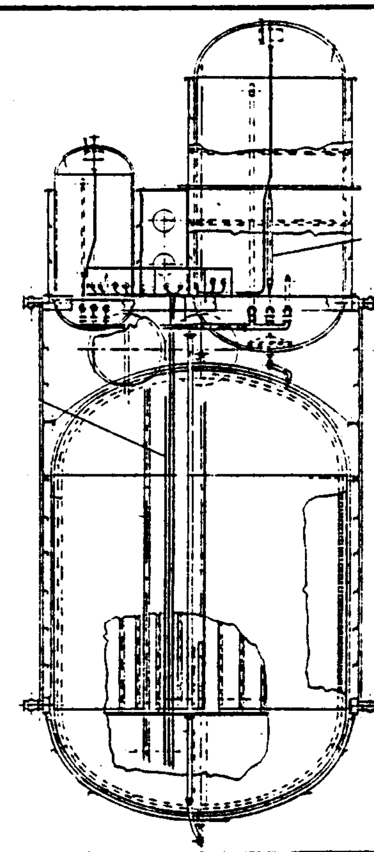


Figure 1-3. Experiment Design Summary

Task IV - Experiment Development Plan (See Section 5.0)

Task IV provided the experiment development plan. This included a definition of the ground and flight qualification tests and shuttle installation requirements. It also provided a schedule for design, fabrication, ground testing, and shuttle integration. In addition, it also provided estimated costs for the total experiment development. Figure 1-4 provides the estimated cost spread and cost categories that were developed.

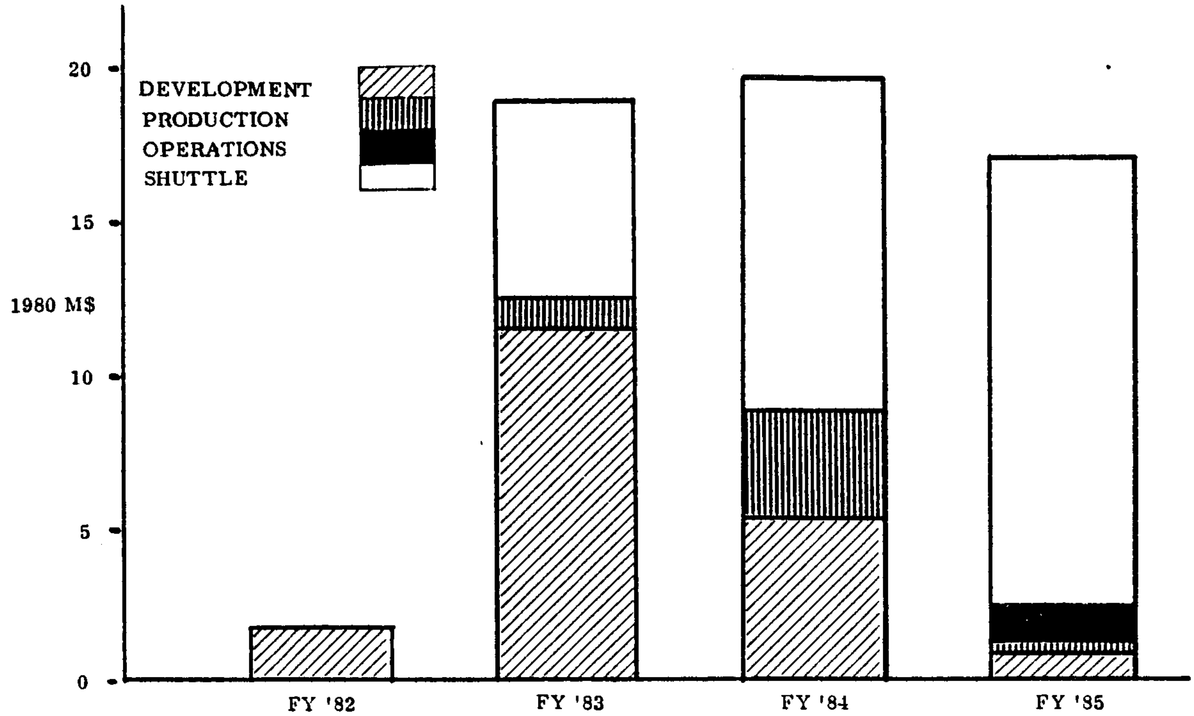


Figure 1-4. Annual Funding Requirements

2

SURVEY OF OTV CONCEPTS AND REQUIREMENTS (TASK I)

This section presents a brief review of Orbital Transfer Vehicle (OTV) concepts being considered for future mission applications. The basic need for in-space propellant transfer is tied directly to the planned use of space-based OTVs. The important OTV programmatic and operational drivers to be considered in the preliminary design of a propellant management experiment are 1) the potential missions requiring OTVs, 2) the planned OTV development and concept evolution; 3) the typical OTV operational interfaces, 4) the likely OTV propellant tank configurations and 5) the typical on-orbit re-supply operations.

These elements along with typical OTV subsystem interface data have been used to justify the pursuit of in-flight propellant transfer experiments. Section 2.1 covers the broad aspects of OTV mission requirements. Section 2.2 covers the potential interfaces between the OTV subsystem and the propellant transfer operation.

2.1 MISSION AND CONFIGURATION REQUIREMENTS

Specific mission requirements defined by the study are limited to operations of an OTV between Low Earth Orbit (LEO) and Geosynchronous Orbit (GEO) using LO_2 and LH_2 as propellants. Additional guidelines limit the vehicle concepts to those that are space-based which implies reusable vehicles refurbished in LEO. These space-based reusable vehicles have applications in the future when space activity is high.

A recent Aerospace Study describes the mission payload requirements through the year 2000. Table 2-1 was taken from that study and indicates the broad cross-section of potential missions and OTV requirements.

Figures 2-1 and 2-2 illustrate several versions of OTVs that might be used in the next 10 to 15 years. Generally these vehicles would have propellant requirements less than 68,000 Kg (150K pounds) per stage.

Prior to committing to a space-based OTV, it would be desirable to perform an experiment which models a Shuttle tanker/OTV configuration and its refueling operation. Figure 2-3 illustrates a tanker/OTV tanking arrangement which for the present appears reasonable. This hard-docked configuration seems to be a better option than the tanker/OTV free-flying undocked arrangement.

Table 2-1. Potential Missions Requiring OTV's*

PRIMARY MISSION	DESTINATION	ESTIMATED SPACECRAFT WEIGHT (lb)	NOMINAL TIME FRAME		IMPULSIVE TRANSFER[1]	
			DEMONSTRATION	OPERATION	ΔV (ft/sec)	ONE-WAY TRANSFER TIME
ELECTRONIC MAIL	GEO	6,000	1984	1987	14,000	6 HR
EDUCATIONAL TV	GEO	10,000	1984	1987	14,000	6 HR
PERSONAL COMMUNICATION	GEO	54,000	1986	1989	14,000	6 HR
DATA ACQUISITION PLATFORM	GEO	15,000	1989	1992	14,000	6 HR
INFORMATION SERVICES PLATFORM	GEO	75,000	1989	1992	14,000	6 HR
GEOSTATIONARY COMMUNICATION PLATFORM	GEO	19,000	1985	1988	14,000	6 HR
ORBITING DEEP SPACE RELAY SAT	GEO	19,000	1983	1986	14,000	6 HR
SOLAR/TERRESTRIAL OBSERVATORY	GEO	22,000	1988	1991	14,000	6 HR
PINHOLE X-RAY/GRAVITY WAVE INTERFEROMETER	L_1	37,000	1988	1991	12,600	4 DAY
NUCLEAR WASTE DISPOSAL	0.86 AU	21,000[2]	-	1987	14,600	170 DAYS[4]
JUPITER BUOYANT PROBE	ESCAPE	6,000	-	1990	21,300[3]	800-900 DAYS
MARS LANDER/SAMPLE RETURN	ESCAPE	62,000	-	1990	11,700 TO 16,700[3]	200-500 DAYS
SAT POWER SYSTEM TEST ARTICLE	GEO	15,000	-	1985	14,000	6 HR
SPACE STATION	GEO	250,000	1993	1996	14,000	6 HR

*NASW-3141

(1) FROM 160 nm/160 nm/28.5 deg ORBIT UNLESS OTHERWISE STATED
(2) INCLUDES KICKSTAGE
(3) EARTH DEPARTURE ONLY (Ref. Boeing Aerospace Company, "Future Space Transportation Systems Analysis Study," Final Report, Vol. 2, D180-20242-2, Dec 31, 1976)
(4) TWO-BURN HOHMANN TRANSFER FROM LEO TO 0.86 AU

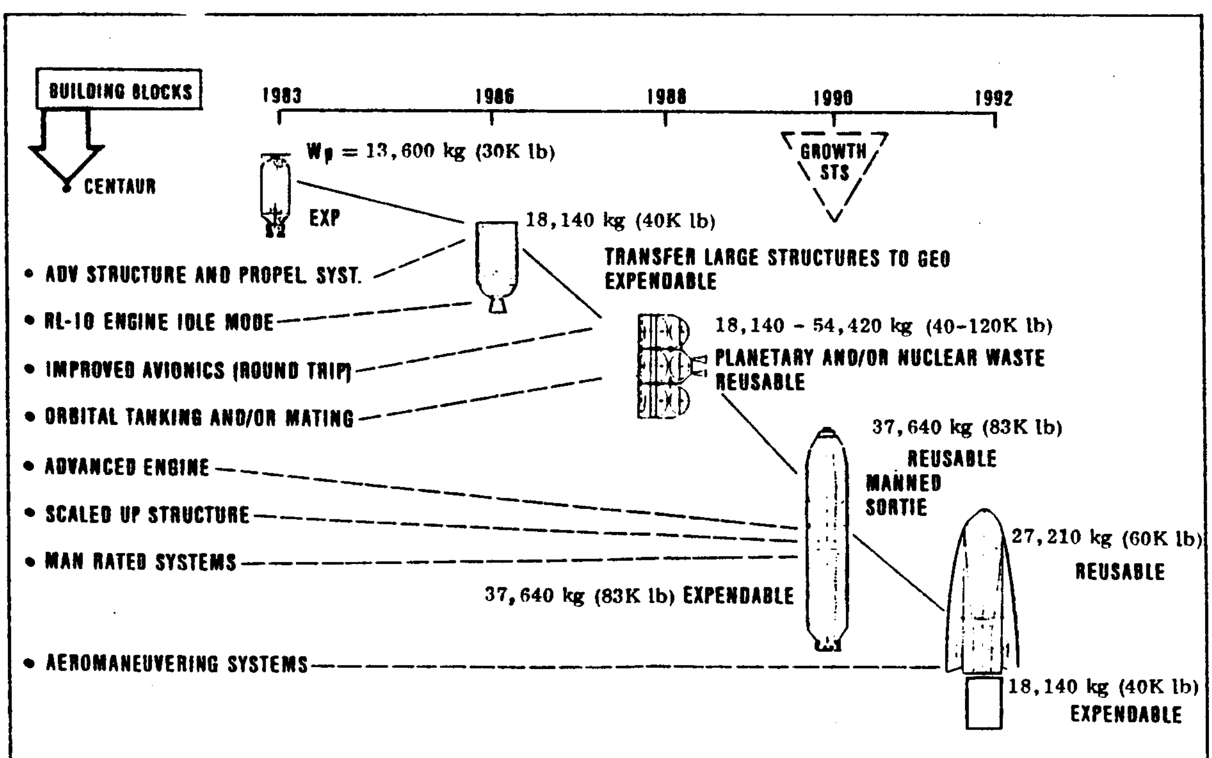
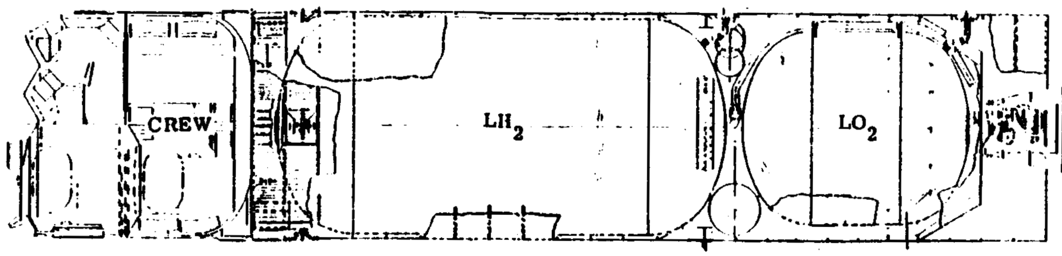


Figure 2-1. OTV Development and Concept Evolution



EACH OF TWO COMMON STAGES:

- FITS IN ORBITER PAYLOAD BAY 4.48 m DIA × 16.46 m LENGTH (14.7 FT × 54 FT)
- 53,000 kg (117,000 LB) HYDROGEN AND OXYGEN (MAY BE TANKED ON ORBIT)
- ENGINES: ASE OR ADVANCED RL-10

Figure 2-2. Typical All-Propulsive OTV Stage Configuration.

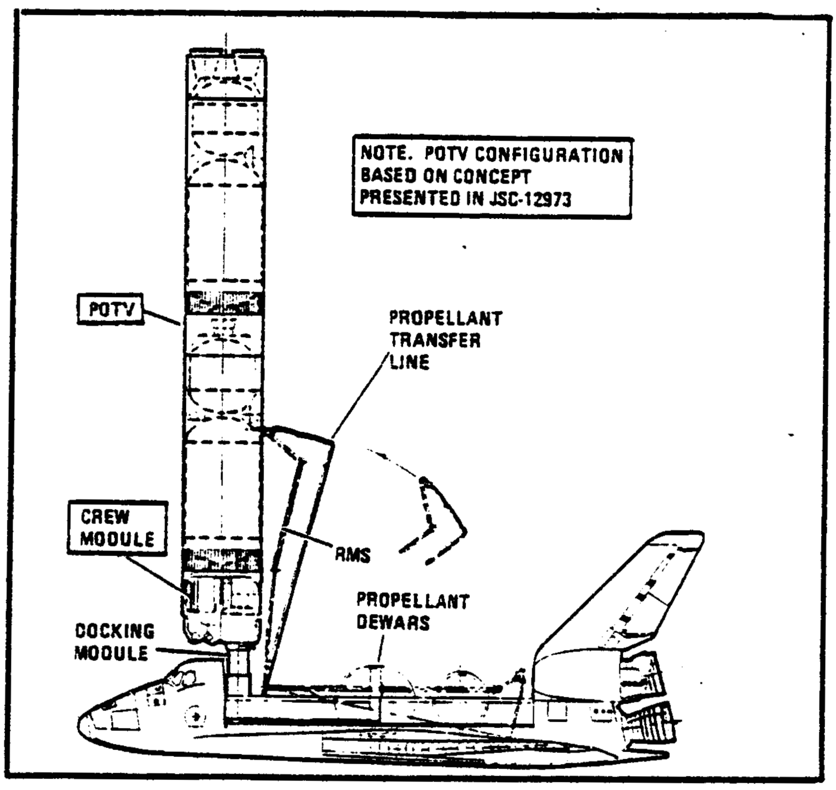


Figure 2-3. Baseline Orbiter Tanking Arrangement.

There are important factors that should be considered for this tanking arrangement other than just the transfer of propellant from one system to another. One requirement is that the OTV propellant tanks must have the capability of receiving propellants both in a warm condition (dry) or in a cold condition (wet). Space-based vehicles may require loading soon after the completion of a mission before all propellants have boiled-off.

Another factor which must be considered in the propellant transfer operation is the propellant loading accuracy. A one percent loading error yields a 6 to 13 percent loss of payload for the dual-or-single-stage OTV, respectively. The zero-gravity tanking accuracy problem is presently unresolved and present technology indicates loading errors of 2 to 4 percent.

2.2 OTV SUBSYSTEM INTERFACE

The preceding candidate OTV concepts were used as the basis for OTV subsystem analyses and subsystem designs. These study elements represent the technology and operational problems that are considered typical of the OTV family that the subsequent preliminary experiment definitions (Task II) will consider.

The space-based OTV will be configured on the basis of mission and space-based requirements. However, because of the volume impact of the Shuttle payload bay, some of these OTVs may be loaded with propellant during their initial launch and, therefore, require the dual capability for propellant tanking both in space and at the launch site.

An OTV propellant transfer technique and subsequent experiment can be influenced by the vehicle configuration; thus, the need to adequately identify vehicle subsystems. A list of subsystems influenced by mission requirements include tank size, pressurization system, propellant acquisition system, insulation system and vent system. Subsystems influenced by space-basing requirements include insulation system and vent system. These fundamental OTV mission and space-based considerations were used to develop a set of typical subsystem designs.

Figure 2-4 shows a LH_2 tankage system for a baseline two stage OTV, that is originally tanked with propellant on the ground and subsequently tanked at a space-based propellant depot. The total system is a cylindrical tank equipped with a fill circuit, non-propulsive vent circuits, a pressurization circuit, an acquisition system and an insulation system.

The tank is a 421.6 cm (166.0 in.) diameter cylinder with elliptical bulkheads at each end. Both bulkheads have plumbing penetration fittings for the vent, fill and electrical circuits. An access opening is provided in the forward bulkhead. The material is 2219-T87 aluminum alloy. The support system is a series of low conductive struts arranged in "V" pairs on the aft bulkhead and a set of tangential drag links located near the girth line of the forward bulkhead. This support system provides for thermal isolation from the main body structure and compensates for dimensional changes between tank and outer body structure.

The fill circuit is a single tubular manifold extending the full length of the tank. The manifold is equipped with two spray fittings in the aft bulkhead. This penetration fitting has a side outlet boss which in turn is connected to the interior of

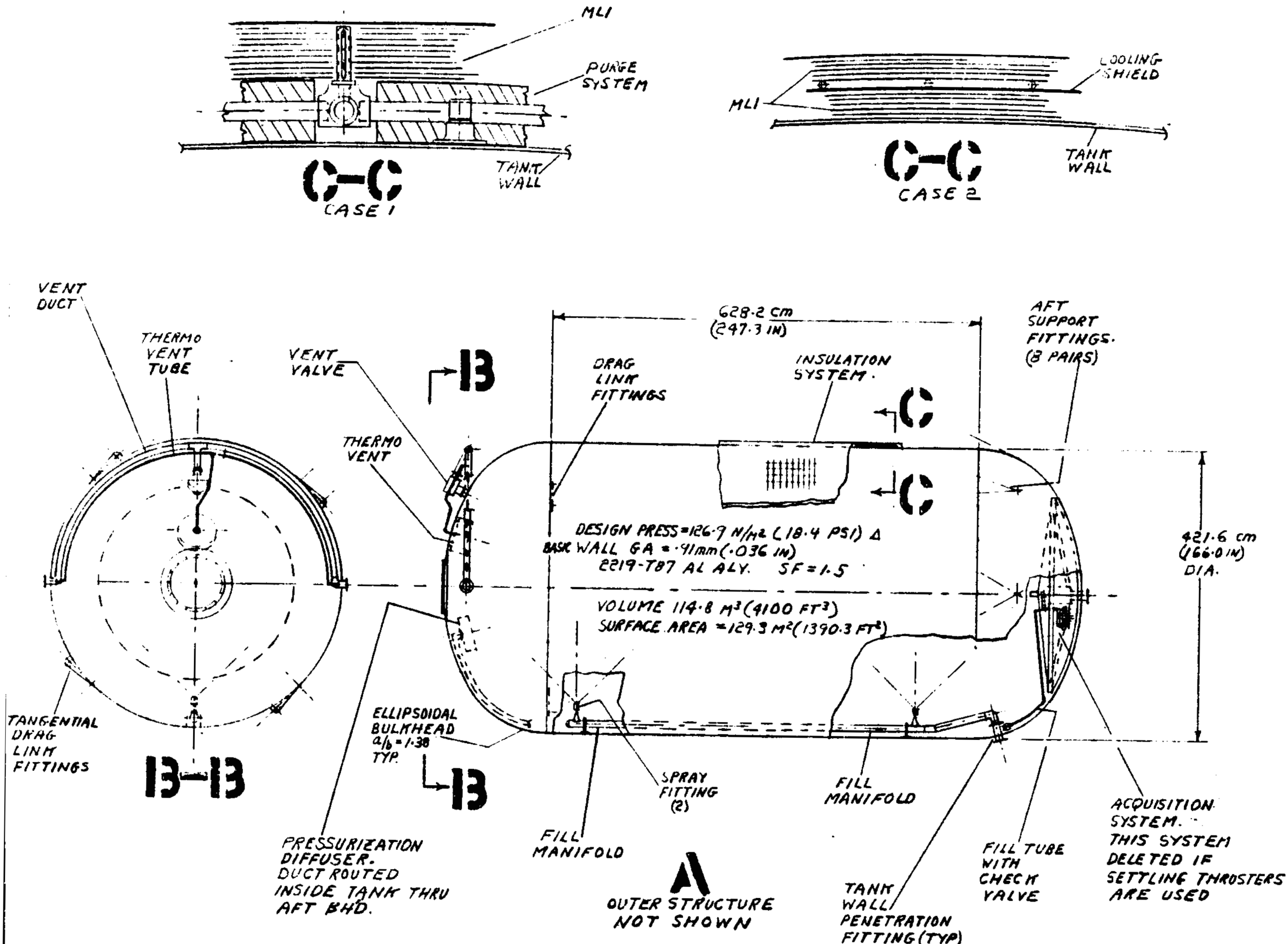


Figure 2-4. OTV Hardware Requirements.

the acquisition device through a check valve and a tube section. The outboard flange of the penetration fitting is attached to a flex duct which routes to a disconnect valve located in the body structure. This flex duct and disconnect valve are not shown on the drawing.

The tank has two vent systems. One system is an external vent valve with a non-propulsive "steer horn" type duct. The second system is a thermodynamic vent device located inside the tank. This device is vented to the outside through a tube which is supported from the "steer horn" vent duct)see View B-B of Figure 2-4.)

3

PRELIMINARY EXPERIMENT DEFINITION (TASK II)

During recent years NASA has developed, both through in-house and contracted effort, an extensive background of low gravity propellant management technology. It was therefore not required nor the intent of this study to expand upon this fundamental technology data base. This comprehensive data base was used as the starting point for the preliminary definition of a large-scale propellant transfer experiment for the Shuttle experiment program.

The preliminary experiment definition study outputs are presented in Section 3.1, the basic analyses, and Section 3.2, the preliminary integrated experiment design concepts.

3.1 ANALYSES

The preliminary experiment definition required that the most impacting areas of concern be analyzed during the initial design stage of the study. Figure 3-1 presents an overview of these preliminary, yet fundamentally important, factors associated with the experiment design. The schematic represents the major hardware elements of the experiment concept and the specific technology areas relevant to the specific hardware items. The general areas selected for analyses during this task are: 1) the childown and 2) the fundamental experiment design and operational drivers. The results presented for this phase of the study were preliminary. The final results presented in Section 4.0 represent those actually used to develop the conceptual designs and program plans.

3.1.1 TRANSFER LINE CHILLDOWN. When chilldown is initiated, liquid and vapor flow in the transfer line together create pressure transients and chugging. These transients, together with the motion of slugs of liquid in the vapor medium, may transmit damaging loads to the OTV during the line chilldown period. Several possible methods of avoiding this difficulty have been suggested. These include propellant preheating, alternate propellant delivery systems during chilldown, and pre-launch chilling.

To obtain an estimate of a reasonable time for the chilling of the transfer lines, an analysis was made assuming liquid enters the line in a saturated condition and evaporates completely prior to leaving the line. Using a flow rate of 0.45 kg/min (1 lb/min), results indicate the LH_2 line can be cooled from 305K to 20K (550R to 36R) in about 14 minutes. Since chilldown time varies inversely with mass flow rate, these results may be used to estimate times for other flowrates within a reasonable range.

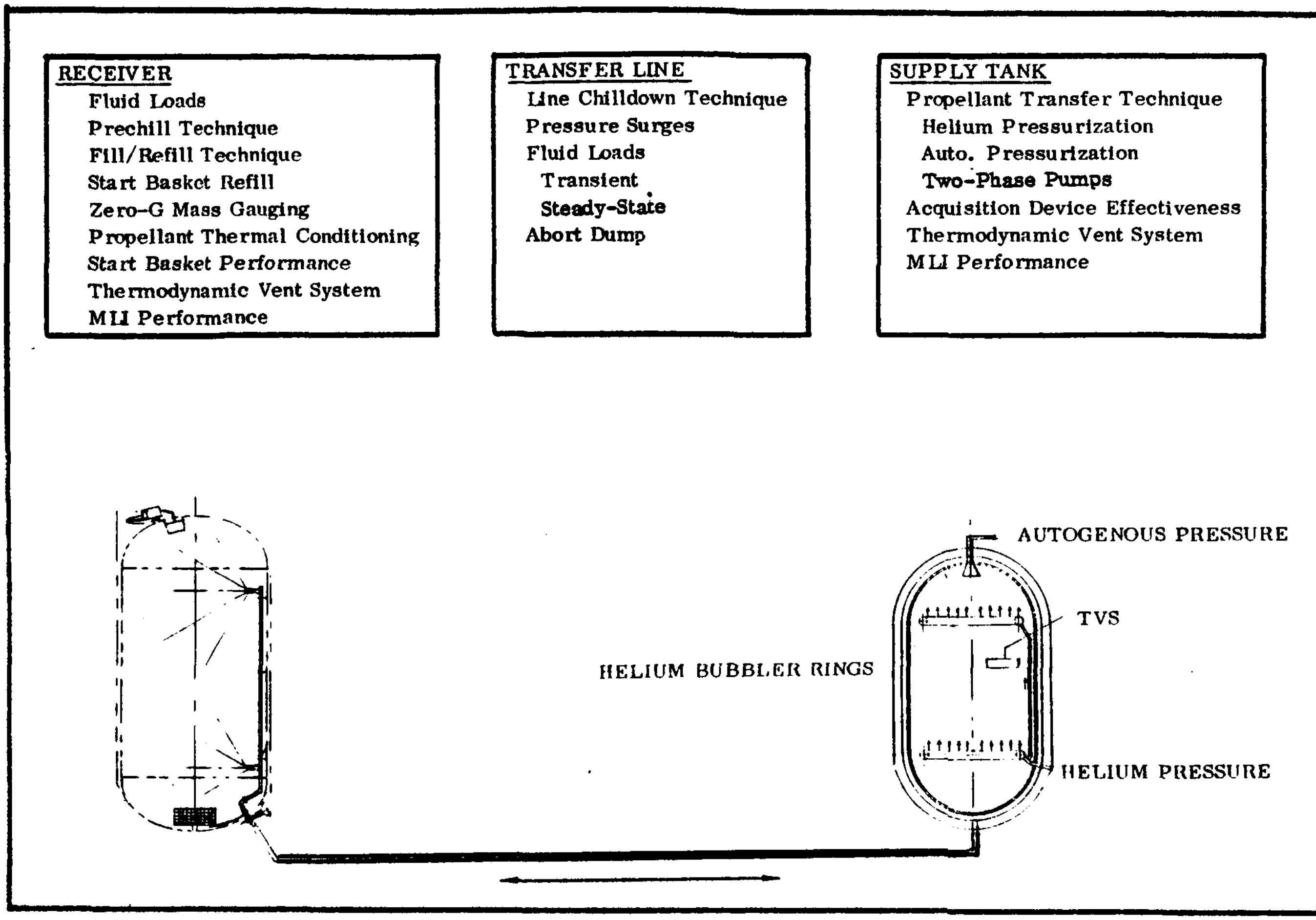


Figure 3-1. Propellant Transfer Areas of Interest/Concern

When the transfer line valve is first opened, cold liquid will contact the hot walls so that a certain amount of vapor and liquid will flow in the line together. Under 1-g conditions, studies have shown that severe pressure transients, some as high as 100% above the supply pressure, can result. These excursions, together with the prospect of slugs of liquid battering the OTV at the hook-up point, give cause for apprehension about loads transferred to the OTV and ultimately to the connecting fixture between it and Shuttle. Hence, it is desirable to avoid formation of liquid slugs, pressure surging, and chugging during the chilldown process.

3.1.2 FUNDAMENTAL EXPERIMENT DESIGN DRIVERS. This preliminary experiment definition study phase stressed analyses dealing with the fundamental characteristics which were major experiment design, operational and cost drivers. Figure 3-2 indicates this overall relationship and presents an overview from which some of the more important drivers were selected for investigation. The following discuss some aspects of the major design drivers - orbiter constraints, experiment operations, and scaling considerations.

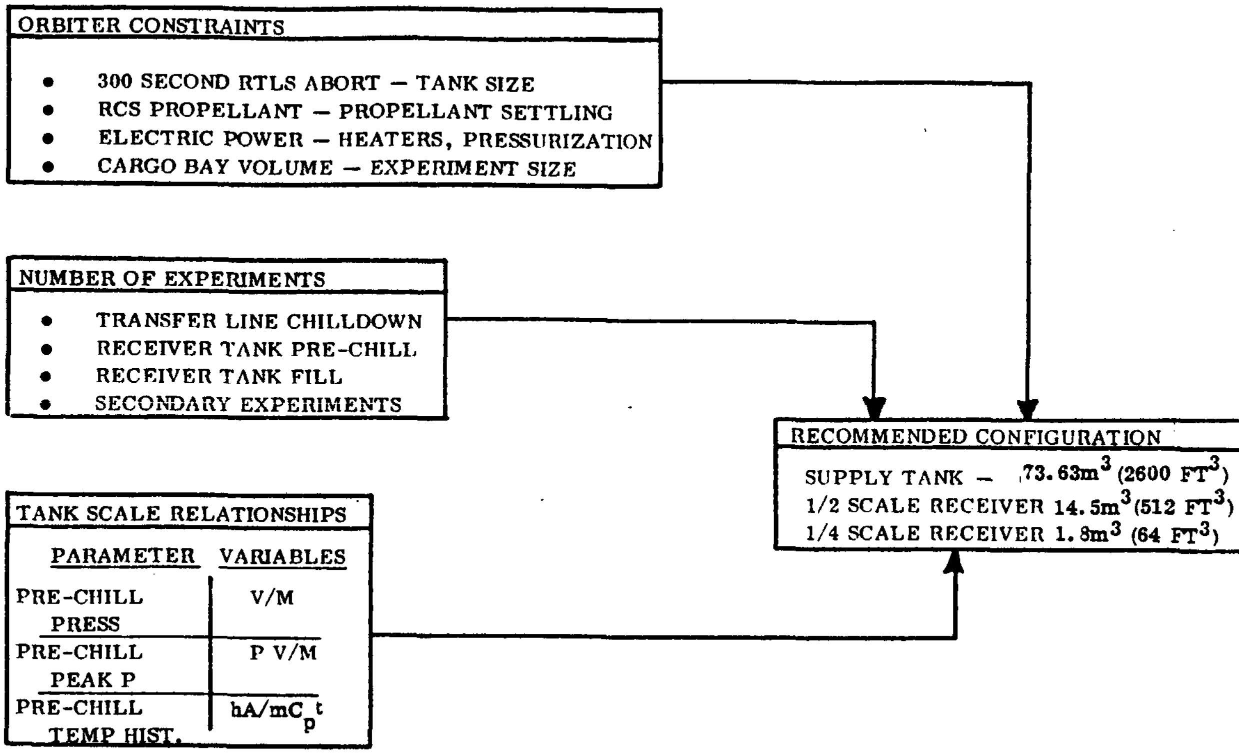


Figure 3-2. Fundamental Design Drivers

<u>Orbiter Constraints.</u> The survey of OTV concepts in Section 2.0 of this report presented the details of a candidate LH_2 propellant tank. The preliminary selection for this phase of the study was a large two stage OTV LH_2 tank as shown previously in Figure 2-4.

Several constraints on the experiment have been imposed by conditions relating to orbiter safety, size, and auxiliary power. First of all, it is required that the capability exist to dump all propellants within 300 seconds at a critical point in the launch phase. The most obvious method to provide this capability is to make a sufficient quantity of helium pressurant available to the supply tank. To allow high flow rates, a dump line with approximately 12.7 cm (5 inch) diameter must be provided.

Fuel available for settling propellants during the conduct of experiments is 1811 Kg (3993 lb). Although additional fuel can be added, it is chargeable to the payload. Electrical power available to the experiments will be approximately 50 kwh based on a 7-day mission. This is a 7 kw average power with peak power limited to 9 kw. Additional 840 kwh fuel cell kits weigh 750-850 kg, with volume available outside the payload boundary but weight chargeable to payload. Of course, orbiter cargo volume also presents a constraint. Finally, there is a minimum number of receiver tank fillings which constitute a complete experiment.

Experiment Operations. It is apparent that the parameter, Pressure·Volume/Mass (PV/M), is important to the early pressure history in tank filling. Preliminary estimates of tank structural mass for various tank sizes, show that the Volume/Mass (V/M) ratio is constant down to approximately 1/2-scale for the OTV receiver tank. It is also apparent from early designs that if two tank scales are selected for the experiment, the orbiter cargo volume constraint will require reducing the largest tank to approximately 1/2-scale. Although the second tank would not have the same V/M ratio, useful information showing the effect of scale would be obtained. There appears to be no good reason to complicate the experiment with more than two receiver tanks.

Options to be considered in the selection of experiment configuration are whether, when, and what quantities of propellant to transfer back from receiver to supply tank. The candidates which appear reasonable are:

1. Single receiver tank with no transfer back
2. Single receiver tank with transfer back
3. Two receiver tanks with transfer back from largest tank (Selected Concept)
4. Two receiver tanks with no transfer back

Candidate number 1 restricts the size of the receiver tank depending on the supply tank size and the minimum number of experiments (runs). On the positive side, it involves the simplest configuration devoid of an array of lines, valves, and fittings. On the negative side, it restricts the amount of useful data obtainable, making minimum use of the on-orbit time available and the money expended to get there.

Candidate number 2 allows a larger receiver tank to be used and more runs to be made. Data showing the effect of tank scale will not be available, settling burns will have to be made, and extra plumbing and pressurization resources will be needed.

Candidate number 3 is advantageous over candidate number 2 in that the effect of tank scale can be assessed and more experiments can be performed. Additional plumbing will be required over that in candidate number 2 and all the negative comments relating candidate 2 and candidate 1 apply here. However, the additional cost (compared with candidate number 2) in terms of space and complexity does not appear to be severe.

Candidate number 4 will result in the same size large receiver as candidate number 1. The principal disadvantage is a reduction in the maximum receiver tank size compared to that of candidates 2 and 3.

The supply tank size has been tentatively fixed at 73.63 m^3 (2600 ft^3). At 95% fill with 138 KN/m^2(20 psia) LH_2 , the tank will contain 4929 Kg (10868 lb) of liquid. It has been established that the abort dump can be accomplished with a 12.7 cm (5-inch) line and 45.4 Kg (100 lb) of 31029 KN/m^2 (4500 psia) helium. Two 101.6 cm (40-inch) diameter bottles would be required for the dump contingency. Each container weighs approximately 136 Kg (300 lb) empty.

A reasonable sizing of the two receiver tank system appears to be a half-scale and quarter-scale combination. The larger size will provide a V/M very close to the full-scale value. There appears to be no reason to increase the size beyond this point. The quarter-scale tank will show the effect of scale on the data at very modest cost in payload volume and use of experiment resources.

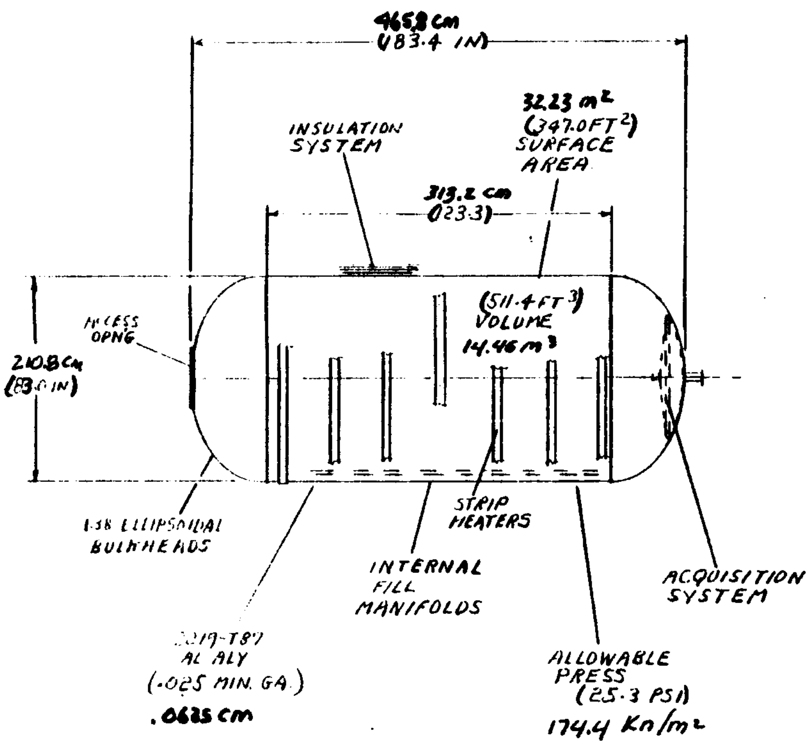
3.2 PRELIMINARY INTEGRATED EXPERIMENT CONCEPT

As a result of the previous analyses and the consideration of the major experiment design drivers, a preliminary experiment design was accomplished. The following briefly describes the receiver tanks and the supply tank which form the major elements of the integrated experiment system concept.

3.2.1 RECEIVER TANKS. A half-scale receiver tank and a weight estimate is shown in Figure 3-3. The basic shell is a 2219-T87 aluminum cylinder with two ellipsoidal bulkheads (a/b = 1.38). The tank is equipped with a multi-layer insulation (MLI) system, outside wall heaters, and acquisition system, and internal fill manifolds. Also included is wall penetration hardware for electrical, plumbing and access.

The basic shell is all welded construction with chem-milled weld zones on both the bulkheads and the cylindrical shell. The entire surface of the tank is covered with MLI applied in gore and cap sections. The wall heaters are circumferential strip types equally spaced along the length of the cylindrical section. The heaters are bonded to the outside surface of the tank wall with the electrical leads packaged into a single cable which penetrates the MLI at one point. The acquisition system is a capillary type device located inside the aft bulkhead. The device is basically a shallow dish equipped with a conical lid, an internal channel assembly and an outlet. The quarter-scale receiver tank is basically the same as the half-scale except for size.

3.2.2 SUPPLY TANK. The supply tank is shown in Figure 3-4. The tank is a 416.6 cm (164.0 in.) dia. cylinder with hemispherical bulkheads. The tank material is 2219-T87 aluminum alloy. The accessories include a channel type capillary acquisition system; thermo vent/internal plumbing for ground and flight vent; dump outlet fitting; a MLI system, access opening, and electrical penetrations. A basic parts breakdown is shown in the weights chart. The tank is supported from an outer body structure which in turn interfaces with the shuttle support journals. The body structure is a 442 cm (174 in.) dia. cylinder equipped with a support adapter at the forward end and a purge enclosure bulkhead at the aft end. Each end of the structure



ITEM (NO SCALE)	WT Kg (lb)
ELECTRICAL RECEPTACLE (TWO)	.54 (1.2)
ELECTRICAL HEATERS	2.72 (6.0)
(.123#/FT²) 20 LAYERS NO PURGE .6 Kg/m²	21.3 (47.0)
ACQUISITION SYSTEM	13.6 (30.0)
15% CONTINGENCIES	16.5 (36.4)
TOTAL	126.7 (279.3)

ITEM (NO SCALE)	WT Kg (lb)
(15# FOR WELD ZONES & BKG) TANK SHELL INC'L. WELD LANDS.	63.5 (140.0)
TANK WALL PENETRATION FTGS AND SUPPORTS	.91 (2.0)
(24.0) I.D. 61. cm ACCESS OPNG RING	2.72 (6.0)
ACCESS DOOR COVER	.91 (2.0)
CRES BOLTS SEALS BOLTS, SEALS & SUPPORT LUGS FOR INTERNAL MANIFOLDS.	.91 (2.0)
INTERNAL MANIFOLDS & FTGS.	2.2 (4.8)
TWO ELECTRICAL BOSSES	.54 (1.2)
TWO ELECTRICAL FTG RETAINER RING	.31 (.68)

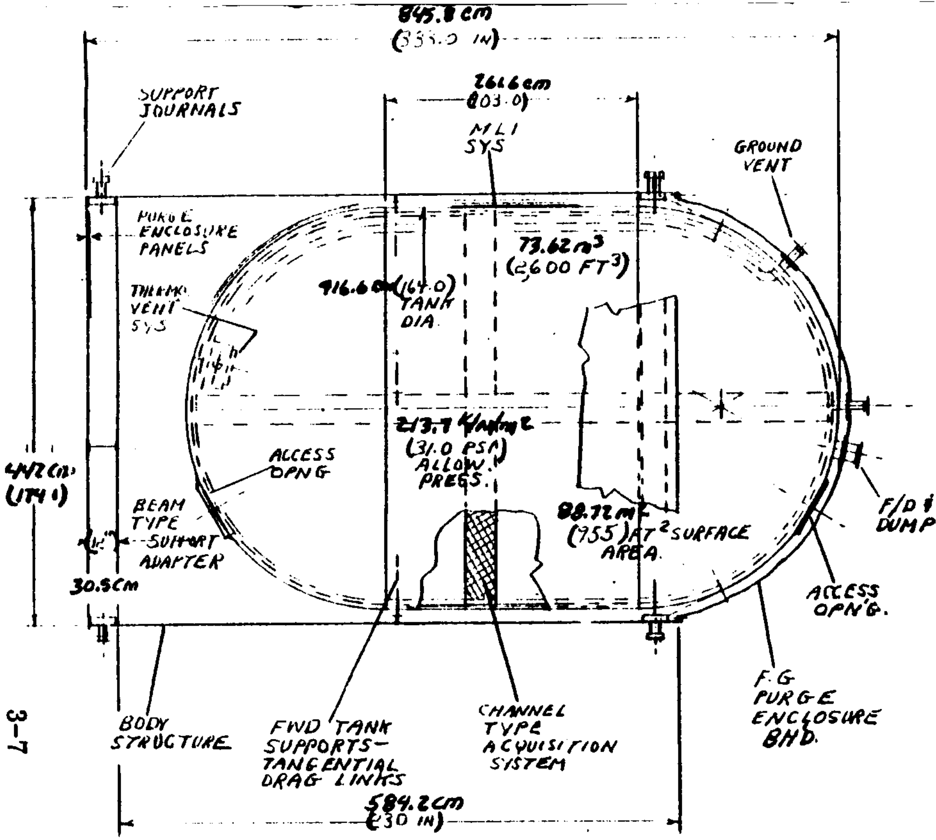
LAYOUT II

ORBITAL REFILL EXPERIMENT.

1/2 SCALE RECIEVER TANK.

J. E. Siden
OCT. 18, 1979

Figure 3-3. Half-Scale Receiver Tank.



ITEM NO SCALE	WT Kg (lb)
PURGE ENCLOSURE BHD (AFT)	45.4 (100.0)
PURGE ENCLOSURE (FWD) F.G.	40.82 (90.0)
SUPPORT ADAPTER	68.0 (150.0)
BODY STRUCTURE PLUS RING & JOURNALS	498.9 (1100.0)
THERMO VENT SYS.	54.4 (120.0)
15% CONTINGENCIES	212.7 (469.0)
TOTAL 1630	(3594.0)

ITEM NO SCALE	WT Kg (lb)
TANK 2219-T87 AL ALY t=.060 27% ADDED FOR WELD LANDS.	475.3 (1048.0)
ACQUISITION SYS	127.9 (282.0)
INTERNAL PLUMBING	27.2 (60.0)
	13.6 (30.0)
ACCESS OPNG RINGS (2)	5.4 (12.0)
ACCESS DOOR COVER (2)	2.72 (6.0)
BOLTS, SEALS & BRACKETS	2.27 (5.0)
ELECTRICAL PENETRATION FTGS	1.81 (4.0)
20 LAYERS TANK INSULATION	53.5 (118.0)

LAYOUT 13

ORBITAL REFILL EXPERIMENT.
LH_2 SUPPLY TANK

L.E. Siden
OCT 19, 1979

Figure 3-4. LH_2 Supply Tank.

has box rings equipped with support trunnions. The support adapter at the forward end has cross beams which interface with the receiver tank truss cages. These beams are covered with flat panels in the areas between the truss cages which complete the purge enclosure.

The overall system installation shown in Figure 3-5 includes the general arrangements and basic plumbing routes. No attempt is made to show all circuits.

The complete assembly including supply tank, body structure and receiver tanks is positioned in the Shuttle so that the aft end is approximately 102 cm (40.0 in.) from the rear payload bay bulkhead. The purpose for this location is to allow room at the aft end for the abort dump manifold and other systems associated with fill, drain, vent and electrical. Most of the lines are routed along the top of the body structure as shown in views A-A and B-B. The transfer line has three straight sections coupled with swivel joints for simulating the operational fill line. At the forward end, the receiver tanks are inter-connected with plumbing and valves so that different transfer modes can be selected. The helium storage bottles with controls and plumbing are supported from the supply tank body structure at the forward end.

The abort dump manifold is a prime driver in the plumbing system due to the quad valve system, vacuum jacketing and large size. An arrangement is shown in view C-C. The manifold is supported from the supply tank body structure with a strut system. A duct section with three axially restrained flex joints routes from the manifold to the Shuttle overboard interface fitting.

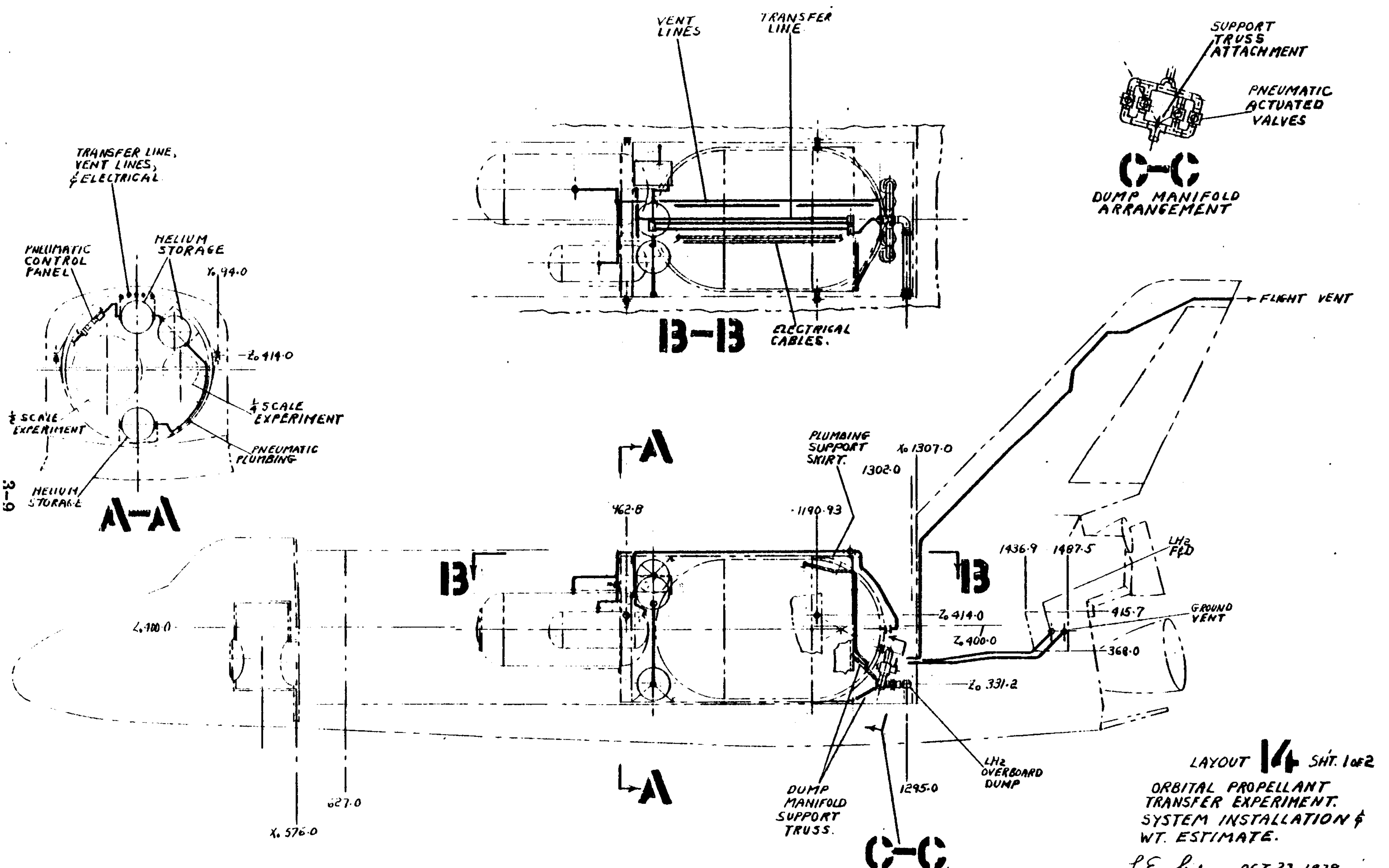


Figure 3-5. Preliminary System Installation & Weight Estimate.

4

SELECTED EXPERIMENT CONCEPTUAL DESIGNS (TASK III)

The preliminary experiment definition presented in Section 3 included as a final checkpoint a design review by NASA which established the direction of this conceptual design task. The intent of this conceptual design is to present a level of experiment concept detail sufficient to provide a credible basis for the program planning tasks that follow.

The experiment conceptual design has three major task elements. Section 4.1 summarizes the detail configurations, layouts, and physical descriptions of the experiment hardware design; Section 4.2 describes the pre-flight procedures of ground applications and design features required to implement the Shuttle safety criteria; and Section 4.3 summarizes proposed propellant transfer experiments in orbit.

4.1 EXPERIMENT DESIGN LAYOUTS/CONFIGURATIONS

The designs accomplished provide a level of detail necessary to: 1) establish feasibility of the experiment concept; 2) provide sufficient detail for defining costs; and 3) to provide a basis for defining the development, testing, and manufacturing schedule. It was not the intent of this study to develop a final detail design of the experiment. The subsequent program plan for implementation of this experiment would include the formalized phase B, C & D activities where the detail design would be an element of the overall program development.

Table 4-1 is a summary of the experiment tankage and support systems that have been conceptually designed. These designs form the basis for the complete experiment module assembly design and the Shuttle installation design.

Table 4-1. Experiment Tankage and Support Systems

Design Element
Supply Tank
Supply Tank Insulation and Purge Systems
1/2 Scale Receiver Tank
1/2 Scale Receiver Tank Insulation System
1/2 Scale Receiver Tank Acquisition Device
1/4 Scale Receiver Tank System
Supply and Receiver Tank Support Structure
Complete Experiment Module Assembly
Experiment Module Shuttle Installation

4.1.1 EXPERIMENT MODULE ASSEMBLY. The complete experiment module assembly shown in Figure 4-1 consists of a support structure, a supply tank, two receiver tanks, power supply unit, remote acquisition interface unit, pneumatic control unit, three helium storage bottles, interconnecting plumbing, an instrumentation system, and wiring. The experiment module assembly contains all systems and interfaces necessary to conduct, monitor and record data for propellant transfer. Also included are provisions for structural, fluid and electrical interfacing with the Shuttle as well as systems for status monitoring during ascent and descent. The equipment is arranged for easy accessibility during factory checkout and KSC ground operations when installed in the Shuttle.

4.1.2 INSTALLATION IN THE SHUTTLE. The main cylindrical structure which contains the supply tank has two aft trunnions, two forward trunnions and two keel fittings which interface with supports on the shuttle. The complete module is placed into the Shuttle payload bay and attached. Referring to Figure 4-2, the centerline of the module is slightly below the payload bay centerline. The purpose for this offset is to provide added space on the top side between the payload bay envelope and the module plumbing. Both plumbing and wiring is located between the stringers and supported with fairleads attached to the tops of the stringers.

4.2 PRE-FLIGHT PROCEDURES

The more significant pre-flight procedures for the propellant transfer experiment involve the ground operations and integration at Kennedy Space Center (KSC), and the experiment design and operational controls imposed by the required STS safety and hazard analysis criteria. Section 4.2.1 provides an overview of the ground operations at KSC. The preliminary safety and hazard analysis for this conceptual design phase of the experiment is presented in Section 4.2.2.

4.2.1 GROUND OPERATIONS. The Propellant Transfer Experiment (PTE) integration and ground operations will take place at the Kennedy Space Center (KSC). Figure 4-3 presents an overview of this planned ground operations scenario.

The following describes typical operations which must be performed at KSC to ready a PTE payload for launch on the Space Shuttle Vehicle (SSV). Payloads for each Shuttle are manifested by JSC into a complete Shuttle cargo. KSC then prepares an integrated ground operations flow for each Shuttle flight. A part of the integration analysis by KSC is to determine whether the payload will be installed in the Orbiter at the Orbiter Processing Facility (OPF) or at the launch pad. Certain hazardous operations cannot be performed in the OPF; consequently, some payloads must be installed at the launch pad. The type of hazardous operations to be performed is the most important criterion in deciding whether a payload will be installed in the OPF or at the launch pad.

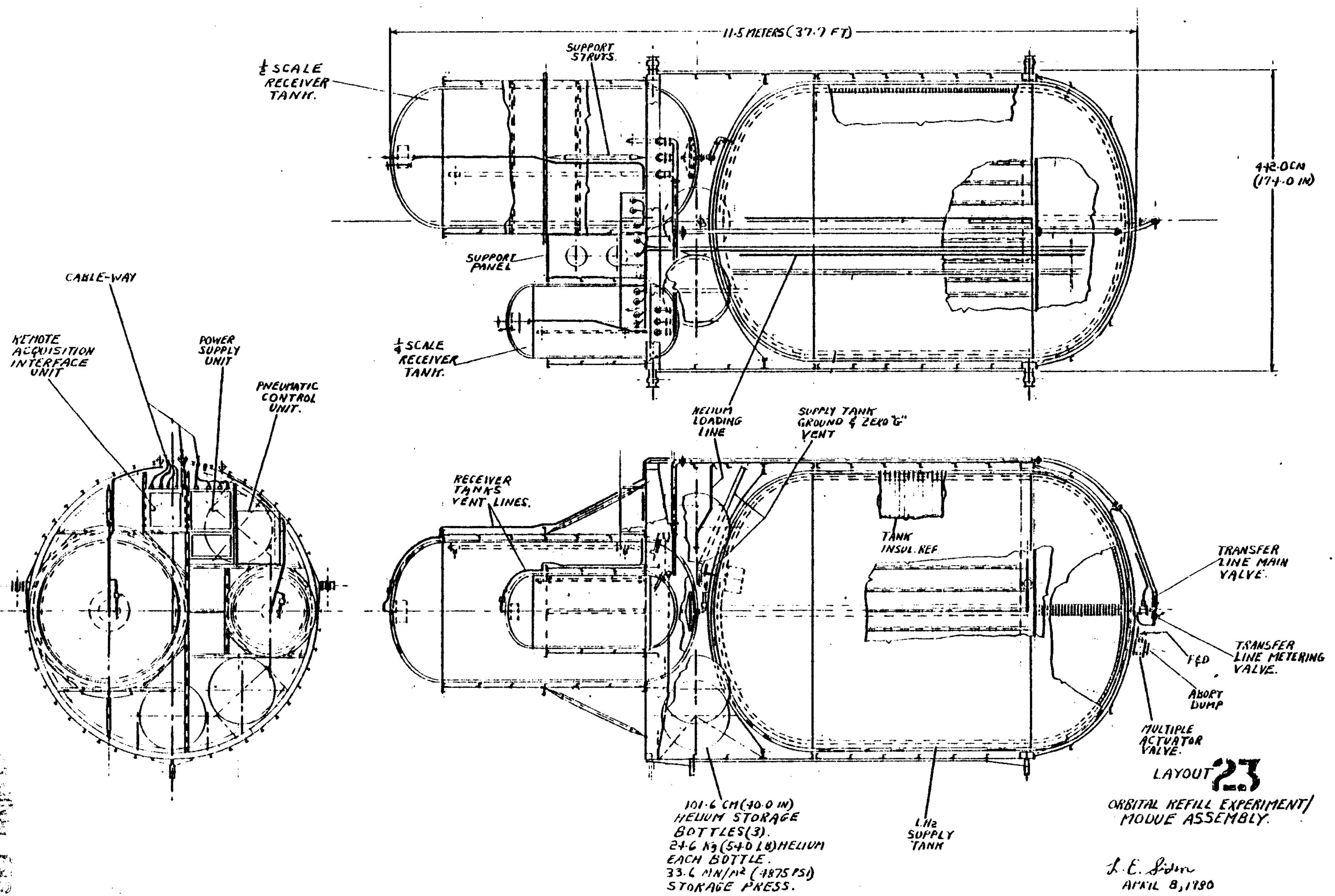


Figure 4-1. Experiment Module Assembly

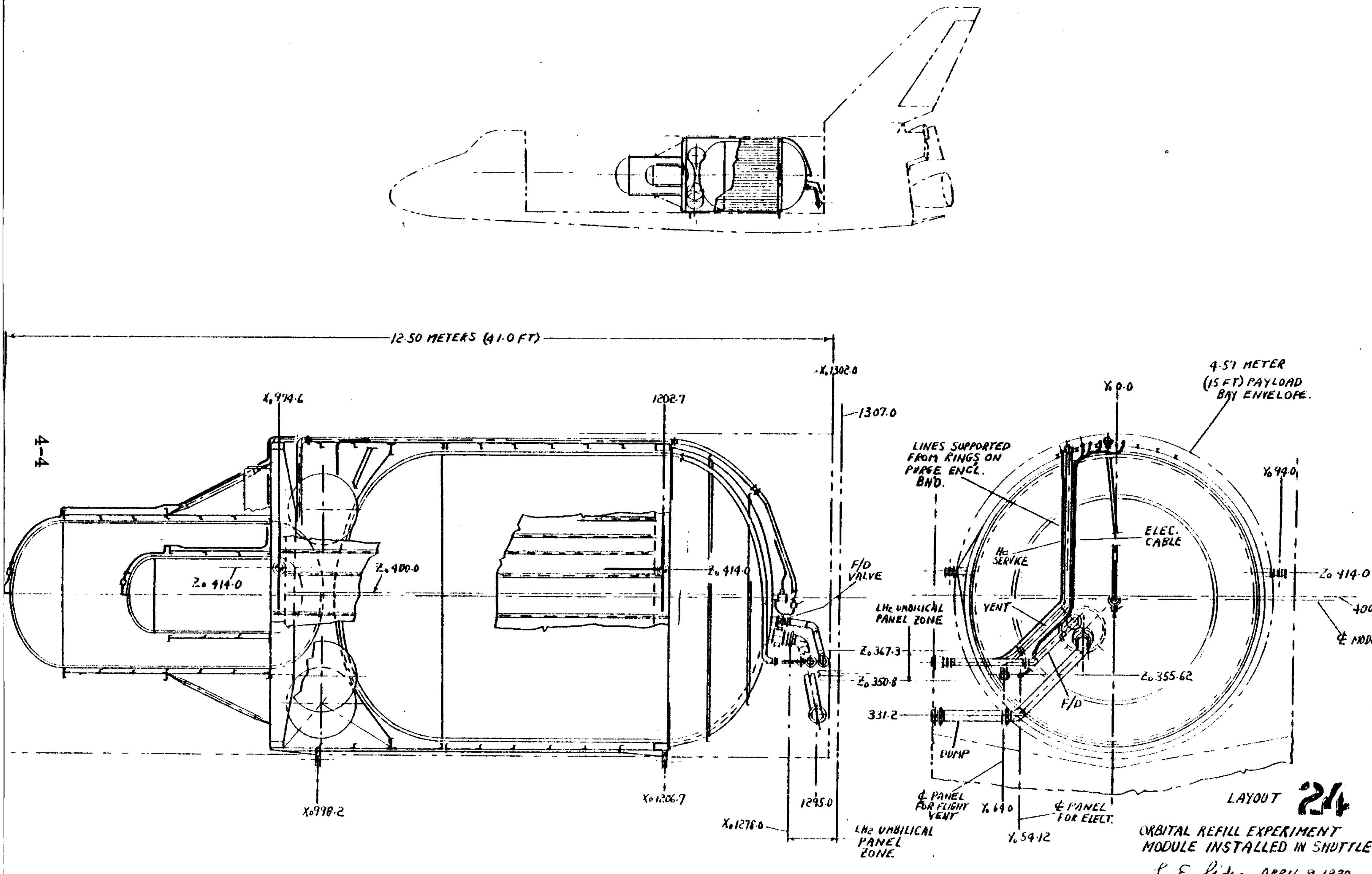


Figure 4-2. Shuttle Installation

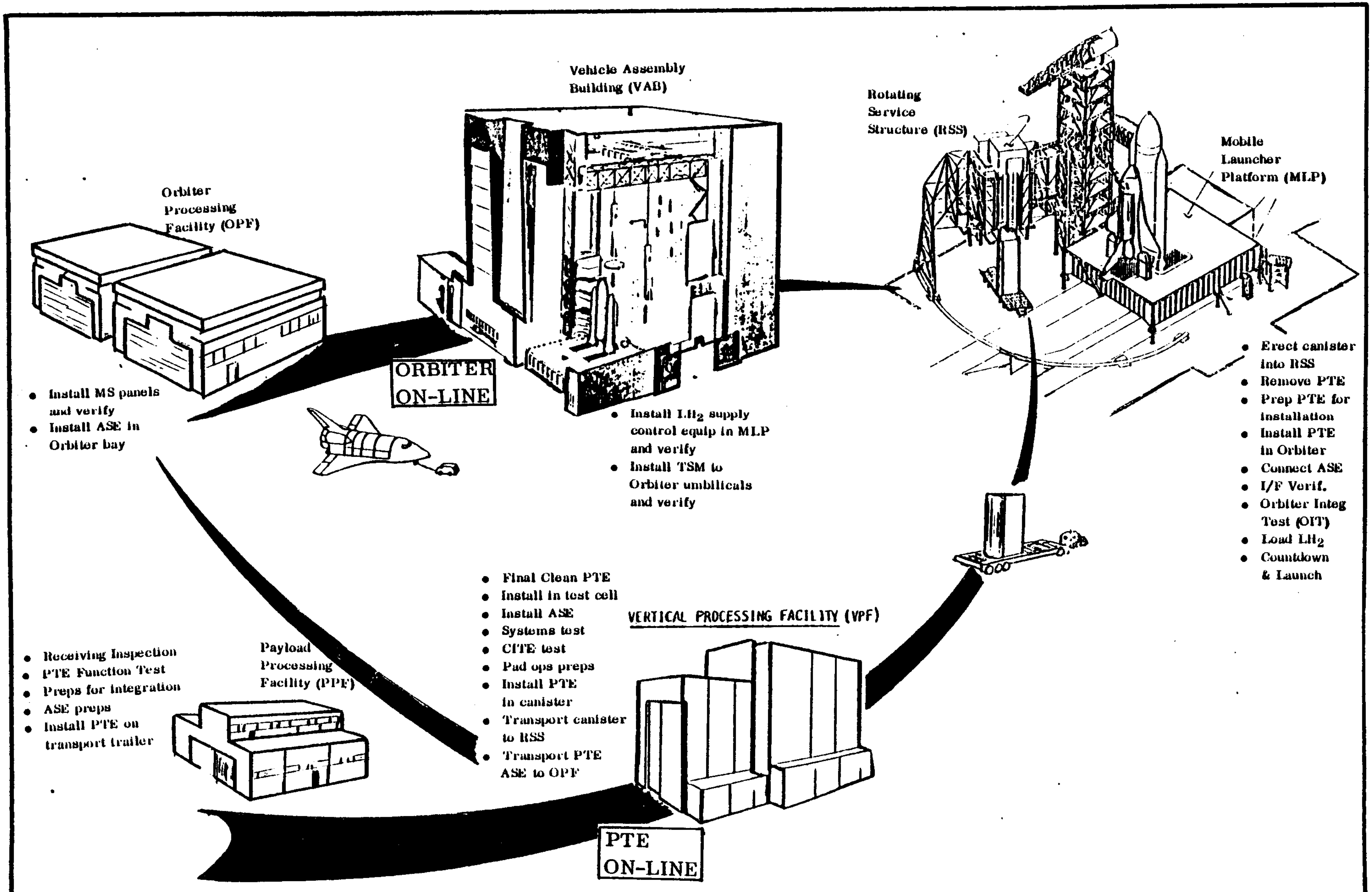


Figure 4-3. Propellant Transfer Experiment (PTE) Ground Operations (KSC Pre-Flight Integration Scenario)

A preliminary analysis of PTE launch site requirements indicates the vertical processing mode of operations, e.g. launch pad payload installation appears to be compatible with PTE requirements.

Some of these requirements, the on-pad propellant loading in particular, were identified during the Centaur-in-Shuttle study and solutions were recommended. These solutions have been incorporated into the PTE scenario to the extent that they apply.

The launch site requirements include the Payload Processing Facility (PPF); the Orbiter Processing Facility (OPF); the Vertical Assembly Building (VAB); and the Rotating Service Structure (RSS). The following summarizes the activities, provisions or interfaces within these site elements.

Payload Processing Facility (PPF):

- LH_2 tanking supply and control system
- PTE transporter
- Transport covers
- Handling GSE
- Electrical interface checkout equipment

Orbiter Processing Facility (OPF):

- Provisions for installing Orbiter cabin located PTE remote control panels
- Provision for installing fluid lines connecting PTE and Orbiter T-0 umbilicals

Vertical Assembly Building (VAB):

- Connecting cables between PTE and CITE launch control center
- Provisions for remote control of PTE LH_2 and He tanking and checkout

Rotating Service Structure (RSS):

- Electrical power for PTE-peculiar GSE
- GHe interface for purging operations

It is apparent that most of the major launch site facilities required for the PTE are presently available at KSC. There are no significant unique requirements. Other facility elements specifically required to support future OTV operations such as the LH_2 tanking and helium pressurization control skids would become available to support any needs of the PTE program.

4.2.2 PRELIMINARY SAFETY AND HAZARD DESIGN ANALYSIS. In order to insure the design of an operationally safe experiment, specific NASA safety and hazard guidelines were used as an integral part of the design effort. The intent at this conceptual stage of the experiment design development was to highlight these safety and hazard guidelines which directly relate to major operational, or design decisions.

Figure 4-4 lists the safety guidelines that were used during the conceptual design phase of the program. Examples of the design and/or operational compliance review sheets are summarized. The major safety design drivers defined are also highlighted.

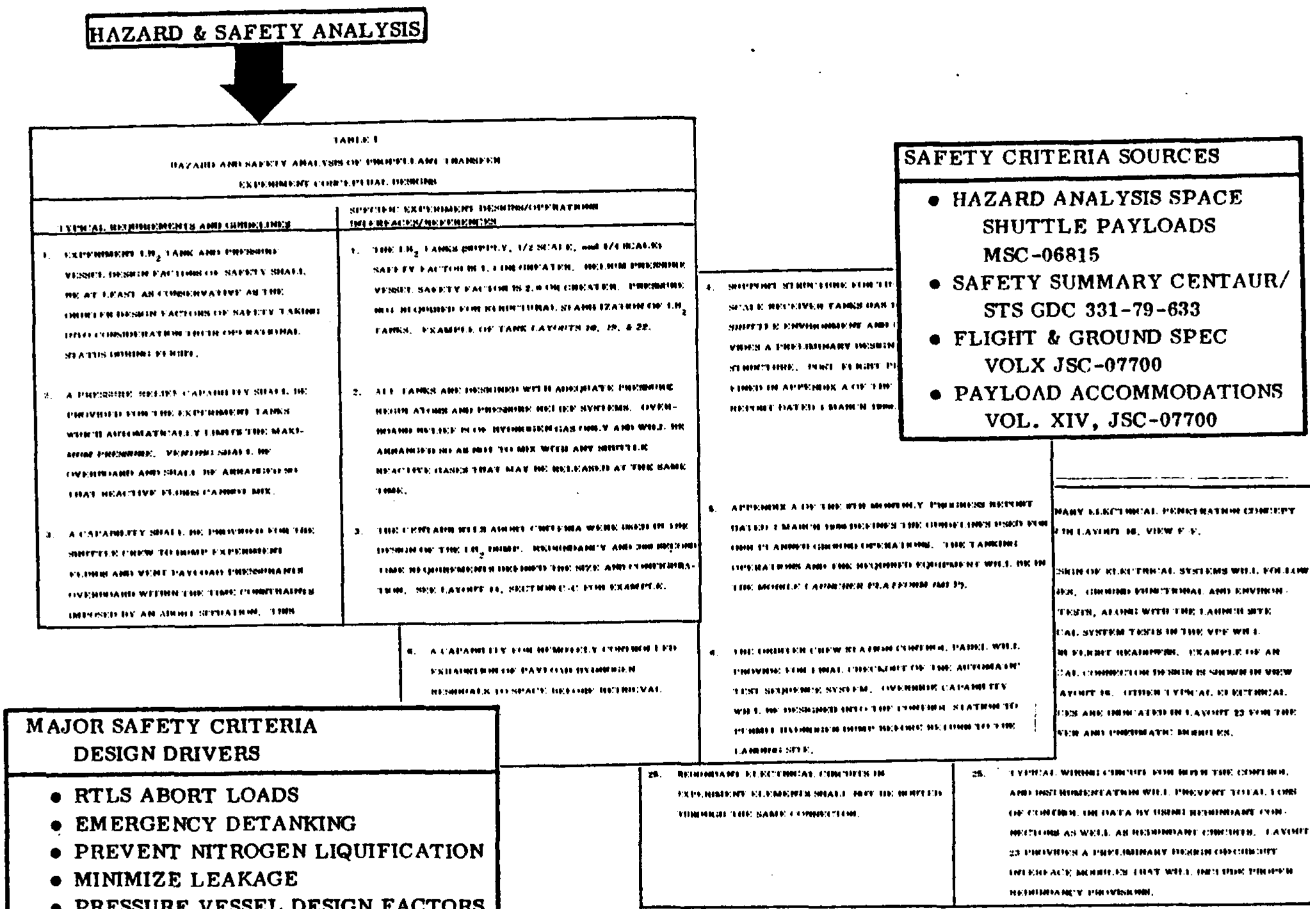


Figure 4-4. Pertinent Safety/Design Interfaces

4.3 TYPICAL EXPERIMENT CONCEPTS

The preliminary experiment analyses and definitions were channeled during this task to emphasize typical instrumentation and control procedures. Figure 4-5 is a total system schematic showing the location and identification of all sensors, valving, plumbing and propellant tanks.

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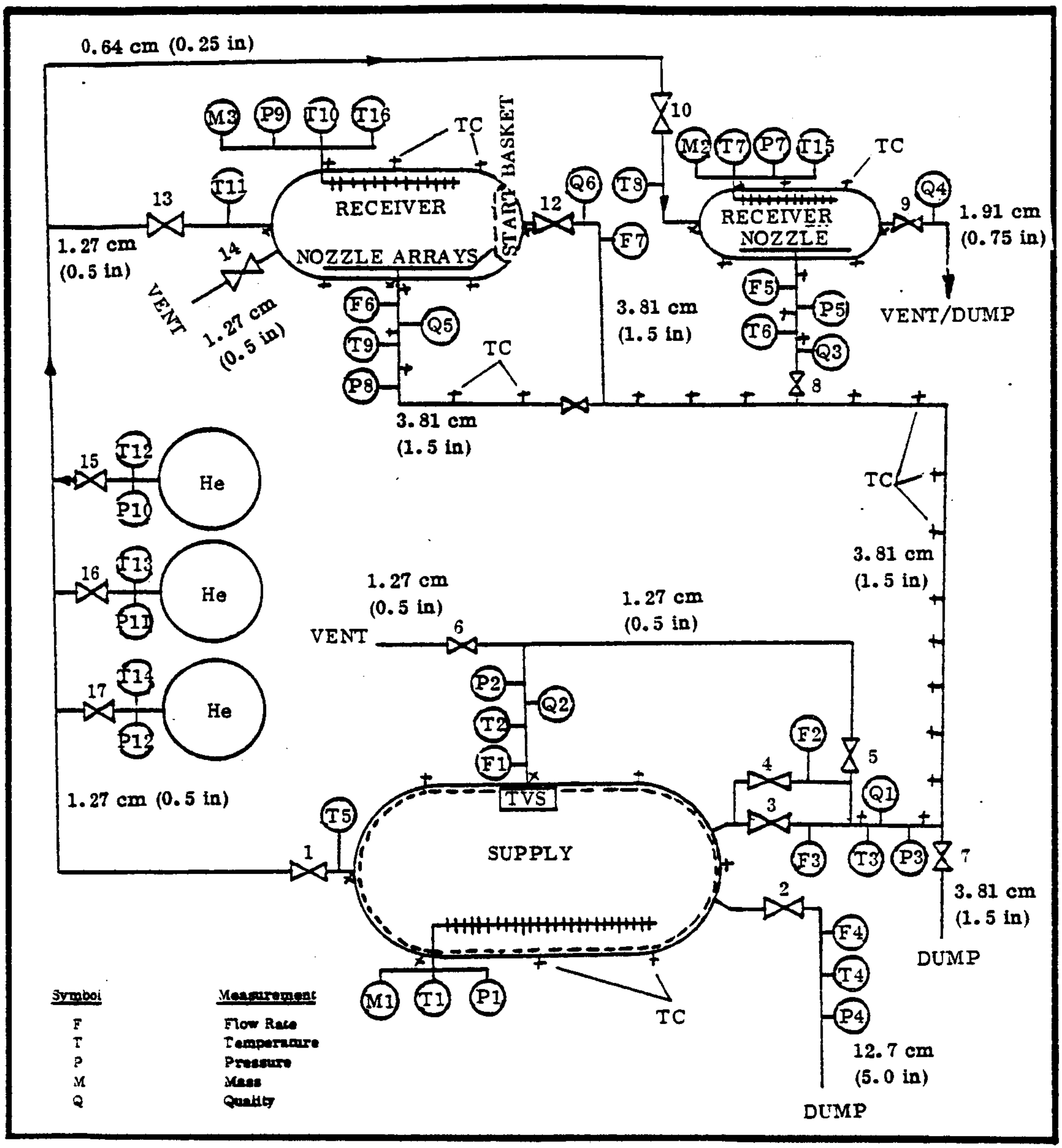

Figure 4-5. Experiment Flow Schematic and Instrumentation Location

The individual test procedures and instrumentation needs that have been defined are summarized in Table 4-2. These tests are typical of the family of tests that the experiment hardware can accommodate and are not meant to be a final selection. The three primary experiment areas of: transfer line chilldown; receiver tank pre-chill; and receiver tank fill also provide opportunities to simultaneously investigate many of the secondary experiment goals. In addition, specific ancillary experiments as well as the sensor requirements are defined.

Table 4-2. Typical Experiment Concepts

<u>Test Procedures</u>
Transfer Line Chilldown
Receiver Tank Pre-Chill
Receiver Tank Fill
Secondary Experiments
- Start Basket
- Helium Pressurization
- Emergency Dump
- MLI & TVS

5

EXPERIMENT DEVELOPMENT PLAN (TASK IV)

This section summarizes the study effort directed toward the definition of program development plans, schedules, and cost estimates of the flight experiment. The objective of the program planning requirements is to produce a program master schedule and costs suitable for advanced planning applications.

5.1 PROGRAM PLANS AND SCHEDULES

A preliminary program development master schedule has been prepared based on the flight experiment definition from Task III and the programmatic groundrules and assumptions discussed below. The project schedule is summarized in Figure 5-1.

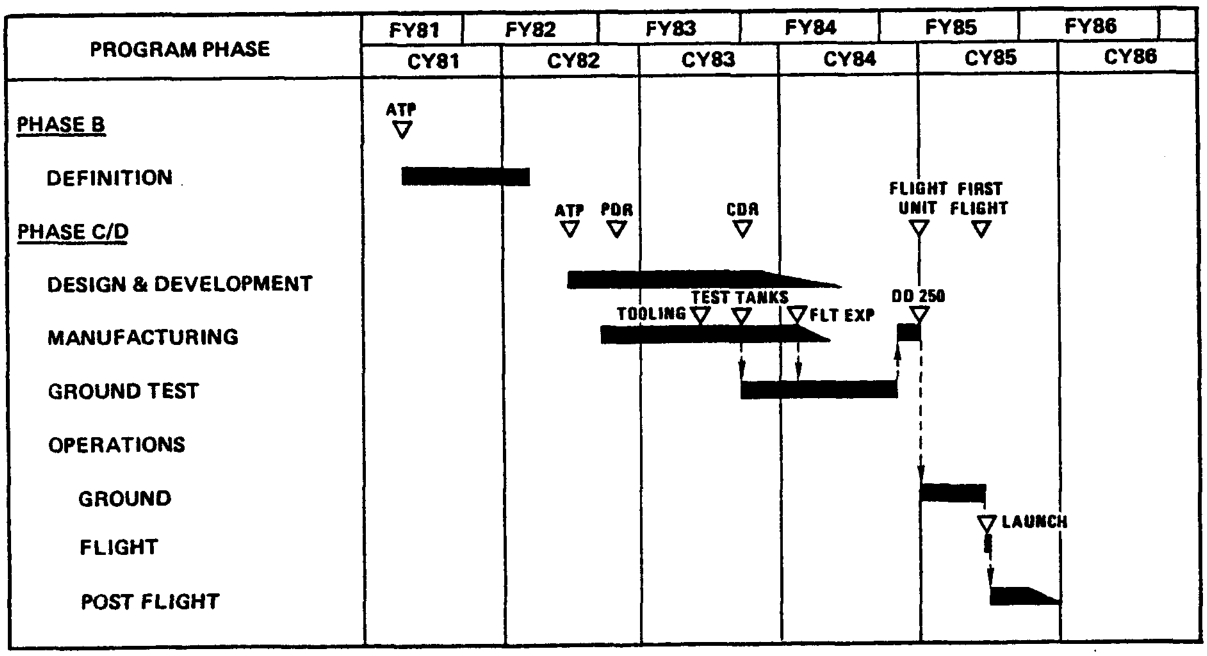

Figure 5-1. PMT Schedule Summary

5.1.1 APPROACH. The approach used to develop this schedule is first to establish the overall program milestones. All major functional task areas were then identified together with the necessary sequence of major activities and events. These were to include the complete sequence of functions and tasks required for each of the principal phases: experiment development and test, flight article fabrication, and operational flight. Once these major milestones and tasks were identified, detailed program milestones, task durations and other pertinent data were laid out in the master program schedule. The key activities of each identified functional task area discipline show time phased relationship to each other and to the external program milestones such as Shuttle activities. Thus, the interfaces and relationships between these activities and the program milestones were identified. This program master schedule therefore serves as a focal point for displaying and evaluating of interface constraints and time critical elements.

5.1.2 GROUNDRULES AND ASSUMPTIONS. The following groundrules and assumptions were used during the development of the program master schedule:

1) The initial experiment flight would occur in mid-CY 1985.

2) A Phase B Definition Study would precede the Phase C/D.

3) All system level development and qualification testing is conducted using the flight article which is refurbished prior to the flight (no complete system level prototype, engineering test model, qualification article or backup flight article is procured).

4) One dedicated set of tanks is required for ground testing during the tank development phase.

5) All purchased components are assumed close to or aerospace flight qualified and only minor modification and/or testing is required. New fabricated or procured components require normal design, analysis, and qualifications to meet the STS payload requirements.

5.1.3 PROGRAM MILESTONES. The summary Propellant Management Technology (PMT) Experiment Schedule for development, manufacturing, and ground and flight test is shown in Figure 5-1. The overall Phase C/D Design and Development schedule provides for a 36-month development program from Authority to Proceed (ATP) in mid-CY 1982, to the initial flight of the experiment (mid-CY 1985). A three-year period was selected as reasonably representative for an experiment such as this. A Phase C/D for a complex vehicle such as an upper stage typically extends for about four years. This experiment might be comparable to a single subsystem of an OTV and therefore the necessary sequential integration and testing would not be nearly as demanding time-wise as a full vehicle program.

5.2 EXPERIMENT COST ESTIMATE

A cost analysis of the propellant management technology experiment (PMTE) has been conducted and the results are presented herein. These data represent preliminary top level estimates that can only reflect the program definition work performed to date and, therefore, cannot be considered complete or final. They do, however, represent a reasonable estimate based on information available at this time and are useful for planning purposes.

5.2.1 WORK BREAKDOWN STRUCTURE. The Work Breakdown Structure (WBS) contains all program life cycle elements categorized or sorted into several levels of hardware and task or function-oriented end items. The resulting format is displayed for each major program phase, including project development, flight article production, and operational test flights. The WBS serves as the basic format for all cost reporting and programmatic data, and to organize, plan, and manage the subsequent program. A preliminary WBS for the PMTE project was prepared.

5.2.2 COST METHODOLOGY. A cost work breakdown structure was developed that includes all elements chargeable to the Propellant Management Technology Experiment Project for each of the program phases, i.e., development, production, and operations. This cost WBS sets the format for the estimating model, the individual cost estimating relationships (CERs), cost factors or specific point estimate requirements, and, finally, the cost estimate output itself. Cost estimates are made for each element, either at the WBS breakdown level shown or one level below in certain cases. These estimates are accumulated according to the WBS to provide the required development, flight article production, and first flight operations costs.

Ground Rules and Assumptions

The following general ground rules and assumptions were used in estimating the costs presented herein.

a. Costs are estimated in current/constant FY 1980 dollars.

b. No prime contractor fee is included in these estimates.

c. Costs are estimated for nonrecurring, recurring production, and recurring operation phases. The costs include all facility payload-related costs incurred from the start of Phase C/D (development phase) through a single (first) launch of the experiment including orbital monitoring and data acquisition.

d. All system level development and qualification testing is conducted using the flight article which is refurbished prior to flight.

e. One dedicated set of test tankage is required for ground test during tank development tests.

f. Most purchased components are assumed off-the-shelf and close to or aerospace flight qualified with only minor modifications or testing required. New components require normal design, analysis testing and qualification.

g. No new facilities will be required chargeable to PMTE payload.

h. NASA IMS and Program Office costs are excluded.

i. This cost data is for planning purposes only.

5.2.3 COST ESTIMATE. The resulting nominal cost estimates for the experiment are summarized in Table 5-1 for the experiment hardware complement and for the complete experiment program. The costs are constant FY 1980 thousands of dollars and exclude prime contract fee. The experiment hardware estimates identify costs for both component development (design, modification, test article procurement) and component test and qualification.

Table 5-1. PMTE Program Cost Summary

COST ELEMENT	COST (FY '80 M$)		
	DEVELOPMENT	UNIT PRODUCTION	OPERATIONS
PMTE EXPERIMENT PROGRAM	19.04	4.75	32.95
PMTE PAYLOAD	19.04	4.75	1.19
FLIGHT HARDWARE	(13.06)	(4.52)	—
SYSTEMS ENG. & INTEGRATION	(1.56)	—	—
SYSTEM TEST	(3.17)	—	—
GSE	(.34)	—	—
OPERATIONS	—	—	(.63)
MAINTENANCE & REFURB.	—	—	(.50)
FACILITIES/STE	(0)	(0)	(TBD)
PROGRAM MANAGEMENT	(.91)	(.23)	(.06)
STS USER CHARGE	—	—	31.76
T/DA USER CHARGE	—	—	TBD

This total experiment program includes software, Ground Support Equipment (GSE), and initial spares. Other wrap-around costs include facility level design and analysis, system engineering and integration, facility level testing, and project management. The operations costs include support operations and logistics, ground operations off-line and on-line, and post-mission operations, and mission operations (mission control data handling/processing and mission support). Post-flight maintenance and refurbishment have been excluded in this estimate as were any reflights or payload update or modifications. No required facilities were identified chargeable to this experiment.

As may be seen, experiment hardware (component) development may be expected to cost about $13M, and the flight hardware production and/or procurement cost is estimated at about $4.5M. The remaining cost elements bring the development and flight unit cost to $19M and $4.8M, respectively, for a total acquisition cost of about $23.8M. The flight mission will cost about $1.1M per flight exclusive of Shuttle transportation charges. The user charge for a dedicated Shuttle flight will vary upward from $31.8M depending on flight time and other optimal services required. The total program cost is then about $56.7M. The confidence limits on this estimate are judged to have an uncertainty of about -10 percent to +20 percent for the PMTE payload portion depending upon the design requirements imposed. These cost uncertainties are shown below.

Cost Uncertainties for PMTE Payload

Estimate	Development	Unit
High	$15.67M	$5.42M
Nominal	$13.06M	$4.52M
Low	$11.75M	$4.07M

6

CONCLUDING REMARKS

The propellant management technology experiment area, under the direction of NASA/LeRC, has systematically investigated experiment designs from the small Spacelab rack mounted experiment to the large Shuttle payload bay installation of this current study.

The "In-Space Cryogenic Fluid Management R&T Ad-Hoc Planning Committee" composed of various NASA center technical and management personnel recommended in December 1979 to focus the propellant management technology and demonstration program on a mid-sized experiment. This approach presently plans the use of the Martin Marietta designed CFME tank as the basic LH_2 supply source to support a series of pallet mounted experiments in Shuttle payload bay.

The present General Dynamics study describes the largest scale experiment configuration considered for in-space propellant management experimentation. Figure 6-1 indicates some of the basic characteristics of this 11.5m (37.7 ft) by 4.42m (14.5 ft) experiment package. The total wet weight including an energy kit is 8993.6 Kg (19831 lb). The support requirements for this experiment concept are all well within the Shuttle capabilities and constraints.

EXPERIMENT ELEMENT	WEIGHT KG	(LBS)
SUPPLY TANK SYSTEM	752.3	(1652)
1/2 SCALE RECEIVER TANK	131.9	(291)
1/4 SCALE RECEIVER TANK	49.4	(109)
PRESSURIZATION SYSTEM	725.6	(1600)
INSTRUMENTATION & WIRING	181.4	(400)
SUPPORT STRUCTURES	1097	(2419)
CONTROLS, RAU, DISPLAYS	145.1	(320)
TOTAL DRY WEIGHT	3082.7	(6791)
TOTAL WET WEIGHT (LH_2 & He)	8253.5	(18199)
PLUS ENERGY KIT (840 KWH)	740.1	(1632)

SUPPORT ELEMENTS	
RCS PROPELLANT	725.6 Kg (1600 LB)
ELECTRICAL ENERGY	47.4 Kw-h
ORBITAL EXPERIMENT TIME	3 + DAYS
SECONDARY EXPERIMENTS	6

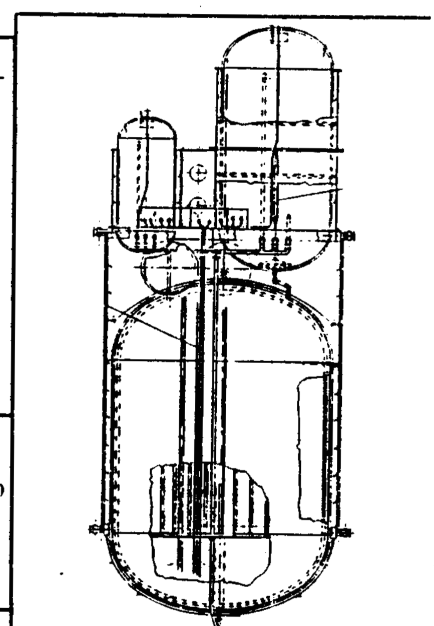

Figure 6-1. Experiment Design Summary

The estimated cost and funding spread to support the design, development, and operations of the experiment program is shown in Figure 6-2. All costs are in FY 1980 dollars and are for planning use only. The total cost estimate is \$56.7M, of which about \$32M are Shuttle user costs.

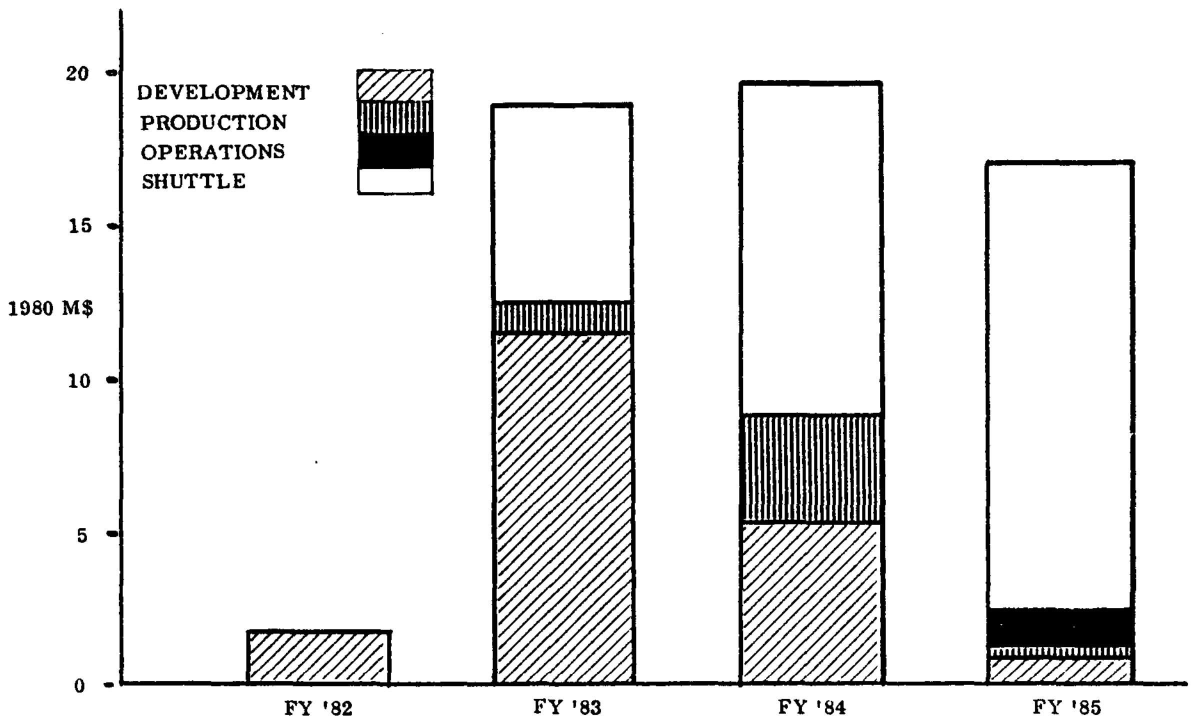

Figure 6-2. Annual Funding Requirements

The conceptual design has addressed the broad needs of propellant management for the future. This future includes a family of OTVs and their operational interfaces which have provided the basis of the experiment design features. The primary experiment objectives have been satisfied with a design that also provides the flexibility needed to be responsive to new and unforeseen requirements of the future.

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15. Supplementary Notes

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16. Abstract

The primary objective of this study was to provide the NASA Lewis Research Center with a conceptual design and development plan for a large scale orbital propellant transfer experiment. The scope of this effort was twofold. First, OTV configurations, operations and requirements planned for the period from the 1980's to the 1990's were reviewed and a propellant transfer experiment was designed that would support the needs of these advanced OTV operational concepts. Second, an experiment development plan was prepared to aid NASA LeRC in the preparation of an overall integrated propellant management technology plan for all NASA centers.

The development program for this experiment starting with the phase C/D effort is three years. The preliminary cost estimate (for planning purposes only) is $56.7M, of which approximately $31.8M is for Shuttle user costs.

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